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INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP00/08801	December 13, 2000	December 22, 1999

TITLE OF INVENTION
IMPULSE RESPONSE ESTIMATION DEVICE AND CHANNEL ESTIMATION METHOD

APPLICANT(S) FOR DO/EO/US
Keiichi KITAGAWA

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Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☐ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☐ is attached hereto (required only if not communicated by the International Bureau).
   b. ☒ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☐ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☐ Certificate of Mailing by Express Mail
23. ☒ Other items or information:

Claim for Priority with PCT/IB/304
PCT/IB/308
PCT/RO/101

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24. The following fees are submitted:.

CALCULATIONS PTO USE ONLY

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

- ☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1000.00**
- ☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO **$860.00**
- ☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**
- ☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**
- ☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**

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CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	8 - 20 =	0	x $18.00	**$0.00**	
Independent claims	2 - 3 =	0	x $80.00	**$0.00**	
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$860.00**	
☐ Applicant claims small entity status. (See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$0.00**	
SUBTOTAL =				**$860.00**	
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Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☒				**$40.00**	
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NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

James E. Ledbetter, Esq.
STEVENS, DAVIS, MILLER & MOSHER, LLP.
1615 L. Street, NW, Suite 850
Washington, DC 20036
Tel.: (202) 785-0100
Fax: (202) 408-5200

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PATENT & TRADEMARK OFFICE

SIGNATURE

James E. Ledbetter, Esq.
NAME

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DESCRIPTION

IMPULSE RESPONSE ESTIMATION DEVICE AND CHANNEL ESTIMATION METHOD

Technical Field

The present invention relates to an equalizer for compensating waveform distortions owing to delays generated in propagation paths for digital signal transmission, and more particularly to an impulse response estimation device to be provided to an equalizer for obtaining impulse responses in the propagation paths.

Background Art

In digital signal transmission, there is a case where transmission characteristics remarkably deteriorate owing to the generation of intersymbol interference in demodulated signals by being influenced by delay waves generated in propagation paths. For compensating the influences of the intersymbol interference in demodulated signals, an adaptive equalizer is used. As an example of the adaptive equalizer, a maximum likelihood sequence estimation type equalizer that is a transversal type filter is described with reference to FIG. 1.

FIG. 1 is a block diagram showing the configuration of a conventional maximum likelihood sequence estimation type equalizer. In FIG. 1, a received signal inputted from

an input terminal 11 is transmitted to a subtracter 12. The subtracter 12 calculates an error between a replica (an estimation value of the received signal) transmitted from a replica generator 13, which will be described later, and the received signal from the input terminal 11 to output an error signal. A square circuit 15 obtains the electric power of the error signal outputted by the subtracter 12.

A maximum likelihood sequence estimation device (MLSE) 16 estimates a transmission sequence having the highest likelihood on the basis of the signal power obtained by the square circuit 15, and the maximum likelihood sequence estimation device 16 outputs the estimated transmission sequence from an output terminal 17 as an estimated signal. Furthermore, the maximum likelihood sequence estimation device 16 outputs the estimated transmission sequence to a channel estimation device 14 and the replica generator 13.

The channel estimation device 14 obtains the impulse response (tap coefficient) of a propagation path on the basis of the error signal outputted by the subtracter 12 and the transmission sequence outputted by the maximum likelihood sequence estimation device 16. The replica generator 13 calculates the replica on the basis of the impulse response obtained by the channel estimation device 14, and outputs the calculated replica to the aforesaid subtracter 12.

When the channel is estimated (i.e. the impulse response of the propagation path is estimated), generally a training signal that is already known by a reception side apparatus is inserted into the front or the center of a transmission signal by a transmission side apparatus, and the reception side apparatus performs initial estimation with a channel estimation device. Consequently, from the point of view of transmission efficiency, the initial estimation is required to have a high speed convergence characteristic.

As a channel estimation algorithm having a superior convergence characteristic, an RLS algorithm is known. By the adoption of the channel estimation device to which the RLS algorithm is applied as the aforesaid channel estimation device, a superior convergence characteristic can be obtained. Accordingly, there are many cases where the channel estimation device to which the RLS algorithm is applied is used as the channel estimation device in the transversal type filter.

However, the conventional transversal type filter has the following problem. Though the aforesaid RLS algorithm can obtain a superior convergence characteristic, because the amount of operations increases in proportion to the square of the number of taps, the amount of operations increases if the number of taps becomes large. Consequently, if the channel estimation device to which the RLS algorithm is applied is used as

the channel estimation device of the conventional transversal type filter, the amount of operations increases at the time of the estimation of a propagation path.

Disclosure of Invention

An object of the present invention is to provide an impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of operations.

The inventor of the present invention turns his attention to the application of a Lattice filter, which has an excellent convergence characteristic while suppressing the increase of the amount of operations, to a channel estimation device in a transversal type filter. However, a tap coefficient estimated by means of the Lattice filter takes a backward reflection coefficient estimation error as an input signal, and differs from a tap coefficient (an impulse response of a propagation path) required by the transversal type filter. That is, it is impossible to apply the Lattice filter to the channel estimation device in the transversal type filter as it is.

Accordingly, the inventor of the present invention made the tap coefficient estimated by means of the Lattice filter convert to the tap coefficient required by the transversal type filter.

That is, according to the present invention, a

transformation matrix is made by the use of a backward reflection coefficient generated by the Lattice filter, and the tap coefficient capable of being applied to the transversal type filter by means of the matrix operation between the tap coefficients calculated by the use of the backward prediction error generated by the Lattice filter and the aforesaid transformation matrix. Thereby the aforesaid object of the present invention is attained.

Brief Description of Drawings

FIG. 1 is a block diagram showing the configuration of a conventional maximum likelihood sequence estimation type equalizer;

FIG. 2 is a block diagram showing the configuration of a maximum likelihood sequence estimation type equalizer equipped with an impulse response estimation device according to Embodiment 1 of the present invention;

FIG. 3 is a block diagram showing the configuration of the impulse response estimation device according to Embodiment 1 of the present invention;

FIG. 4 is a block diagram showing the configurations of the Lattice filter and the tap coefficient calculation section in the impulse response estimation device according to Embodiment 1 of the present invention;

FIG. 5 is a block diagram showing the configuration of a decision feedback equalizer equipped with an impulse response estimation device according to Embodiment 2 of

the present invention;

FIG. 6 is a block diagram showing the configuration of a synchronous establishment device equipped with an impulse response estimation device according to Embodiment 3 of the present invention; and

FIG. 7 is a typical diagram showing a state when a base station apparatus equipped with an impulse response estimation device according to Embodiment 4 of the present invention performs the radio communication in the TDD system with a mobile station apparatus.

Best Mode for Carrying Out the Invention

Hereinafter, the best mode for the implementation of the present invention is described in detail with reference to the attached drawings.

(Embodiment 1)

FIG. 2 is a block diagram showing the configuration of a maximum likelihood sequence estimation type equalizer equipped with an impulse response estimation device according to Embodiment 1 of the present invention. In FIG. 2, a received signal inputted from the input terminal 101 is transmitted to an impulse response estimation device 102 and a subtracter 103 according to the present embodiment.

The subtracter 103 calculates an error between a replica (the estimation value of the received signal) transmitted from the replica generator 107 and the

received signal from the input terminal 101 to output an error signal. A square circuit 104 obtains the electric power of the error signal outputted by the subtracter 103.

A maximum likelihood sequence estimation device (MLSE) 105 estimates a transmission sequence having the highest likelihood on the basis of the electric power obtained by the square circuit 104, and outputs the estimated transmission sequence to an output terminal 106 as a demodulated signal. Furthermore, the maximum likelihood sequence estimation device 105 outputs the estimated transmission sequence to the impulse response estimation device 102 and the replica generator 107.

The impulse response estimation device 102 receives the input of the received signal from the input terminal 101 as a reference signal, and receives the input of the transmission sequence from the maximum likelihood sequence estimation device 105 as an input signal, and further the impulse response estimation device 102 obtains an impulse response of a propagation path on the basis of each of the input signals. Incidentally, the details of the impulse response estimation device 102 will be described later.

The replica generator 107 calculates a replica on the basis of the impulse response of the propagation path obtained by the impulse response estimation device 102, and outputs the calculated replica to the aforesaid subtracter 103. Because the replica generator 107 thereby

can calculate a highly precise replica, the maximum likelihood sequence estimation device 105 can outputs a demodulated signal the influences of intersymbol interference in the received signal on which has been compensated.

Next, the configuration of the impulse response estimation device 102 according to the present embodiment is described by reference to FIG. 3. FIG. 3 is a block diagram showing the configuration of the impulse response estimation device 102 according to Embodiment 1 of the present invention.

In FIG. 3, an input signal sequence, i.e. the transmission sequence from the maximum likelihood sequence estimation device 105 in FIG. 2, is inputted into a Lattice filter 201. The Lattice filter 201 generates a backward prediction error signal sequence and a backward reflection coefficient by the use of the input signal sequence. Furthermore, the Lattice filter 201 outputs the generated backward prediction error signal sequence to a tap coefficient calculation section 202, and outputs the generated backward reflection coefficient to a tap coefficient conversion section 203. Incidentally, the details of the Lattice filter 201 will be described later.

The reference signal, i.e. the received signal from the input terminal 101 in FIG. 2, is inputted into the tap coefficient calculation section 202. The tap coefficient calculation section 202 calculates a tap coefficient "w",

the input to which is the backward prediction error, by the use of the backward prediction error signal sequence from the Lattice filter 201 and the reference signal sequence form the input terminal 101, and the tap coefficient calculation section 202 outputs the calculated tap coefficient to a tap coefficient conversion section 203. Incidentally, the details of the tap coefficient calculation section 202 will be described later.

The tap coefficient conversion section 203, at first, makes a tap transformation matrix shown in the following by the use of the backward reflection coefficient calculated by the Lattice filter 201.

$$\mathbf{L} = \begin{bmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ a_1(1) & 1 & 0 & 0 & & 0 \\ a_2(2) & a_2(1) & 1 & 0 & & 0 \\ a_3(3) & a_3(2) & a_3(1) & 1 & & 0 \\ \vdots & & & & \ddots & \vdots \\ a_M(M) & a_M(M-1) & a_M(M-2) & a_M(M-3) & \cdots & 1 \end{bmatrix} \quad \text{—①}$$

where $a_M(m) = a_{M-1}(m) + \gamma_m a_M{}^*(M - m)$, and "$\gamma_m$" is a reflection coefficient at the m^{th} step of the Lattice filter, and further "*" indicates to be complex conjugate.

Furthermore, the tap coefficient conversion section 203 generates an impulse response of the propagation path by means of the matrix operation using the made tap transformation matrix and a tap coefficient calculated by the tap coefficient calculation section 202, and the tap coefficient conversion section 203 outputs the generated

impulse response from an output terminal 204. To put it concretely, the tap coefficient conversion section 203 generates the impulse response of the propagation path in conformity with the following expression.

$$\mathbf{h} = \mathbf{L}^H \mathbf{w} \qquad \text{—②}$$

where "h" indicates an impulse response of a propagation path and "L^H" indicates a complex inverted matrix of the tap transformation matrix L and further "w" indicates a tap coefficient.

Next, the Lattice filter 201 and the tap coefficient calculation section 202 are described by reference to FIG. 4. FIG. 4 is a block diagram showing the configuration of the Lattice filter and the tap coefficient calculation section in the impulse response estimation device according to Embodiment 1 of the present invention. Incidentally, in the present embodiment, a case where the number of taps is set to be M + 1 is described as an example, but the present invention is not limited to such a case, and the present invention can be applied to cases where the number of taps is altered according to various conditions.

At first, the Lattice filter 201 is described. When Fig. 4 is referred, the Lattice filter 201 has a configuration in which M steps of filters 301 are connected in cascade connections. Each filter 301 is equipped with a delay unit 301, multipliers 302, 304, and adders 303, 305.

At first, an input signal, i.e. a transmission sequence from the maximum likelihood sequence estimation device 105, is delayed for the period of time of one symbol by the delay unit 301 in the first step filter. The input signal before the period of time of one symbol is transmitted to the adder 303 after the input signal is multiplied by the forward reflection coefficient at the first step by the multiplier 302. The signal multiplied by the forward reflection coefficient by the multiplier 302 is added to the input signal by the adder 303. The signal added by the adder 303 is an output signal at the upper row of the first step filter as a "forward prediction error", and is an input signal at the upper row of the send step filer.

On the other hand, the input signal is multiplied by the backward reflection coefficient at the first step by the multiplier 304, and then is transmitted to the adder 305. The signal multiplied by the backward reflection coefficient by the multiplier 304 is added to the input signal before the period of time of one symbol from the delay unit 301 in the adder 305. The signal added by the adder 305 is an output signal at the lower row at the first step filter as a "backward prediction error", and is an input signal at the lower row at the second step filter.

The forward reflection coefficient and the backward reflection coefficient are severally controlled in order that root mean square values of the forward prediction

errors and the backward prediction errors become minimum. By the repetition of a series of the operation in the aforesaid filter up to the M^{th} step, M backward prediction errors by the filters from the first step to the M^{th} step and one input signal to be added, i.e. (M + 1) backward prediction errors in all, can be obtained. The obtained backward prediction errors are transmitted to the tap coefficient calculation section 202. Incidentally, the backward prediction error by the 0^{th} step filter corresponds to the input signal.

Next, the tap coefficient calculation section 202 is described. The backward prediction errors of the filters from the 0^{th} step to the M^{th} step of the Lattice filter 201 are respectively transmitted to a multiplier $306a_0$ to a multiplier $306a_M$ in the tap coefficient calculation section 202. The backward prediction errors of the filters from the 0^{th} step to the M^{th} step are severally multiplied by tap coefficients by the multipliers $306a_0$ to $306a_M$, and then the multiplied backward prediction errors are respectively subtracted from the reference signal by subtracters $307a_0$ to $307a_M$. Thereby an error signal is generated. However, the reference signals at the subtracters $307a_1$ to $307a_M$ correspond error signals generated at the subtracter at the front step severally.

The tap coefficients at the multipliers $306a_0$ to 306_M are adjusted in such a way that orthogonality is kept between the backward prediction errors and error signals

generated by the subtracters being destinations of outputting by each multiplier. For example, the tap coefficient in the multiplier $306a_1$ is adjusted in such a way that orthogonality is kept between the backward prediction error at the first step in the Lattice filter 201 and the error signal generated by the subtracter $307a_1$ being the destination of outputting by the multiplier.

The series of the aforesaid processing by the multiplier and the subtracter is repeated as many as (M + 1) steps. By the repetition of the processing for a symbol time (for a training symbol length at the time of initial estimation), (M + 1) tap coefficients can be obtained. The aforesaid is the details of the Lattice filter 201 and the tap coefficient calculation section 202.

According to the impulse response estimation device having the aforesaid configuration, the Lattice filter 201 converts an input signal sequence to backward prediction errors orthogonalized to each other, and the tap coefficient calculation section 202 estimates tap coefficients the inputs of which are backward prediction errors from the Lattice filter 201. Thereby, the estimation of the tap coefficients can be ended by a small number of times of updating. Because the operations in the Lattice filter 201 and the tap coefficient calculation section 202 do not include matrix operations, by the use of the Lattice filter 201 and the tap coefficient calculation section 202, the tap coefficient can be

estimated with a remarkably small amount of operations in comparison with the case where the RLS algorithm is used.

Furthermore, the tap coefficient conversion section 203 makes a tap transformation matrix by the use of a backward reflection coefficient made by the Lattice filter 201, and performs the multiplication of the tap transformation matrix and the tap coefficient estimated by the Lattice filter 201. Thereby, a tap coefficient applicable to the transversal type filter, namely an impulse response of a propagation path, can be obtained. Although the processing in the tap coefficient conversion section 203 includes a matrix operation, the tap coefficient conversion section 203 does not need a matrix operation at every updating like in the case where the RLS algorithm is used. That is, because the tap coefficient conversion section 203 performs the matrix operation only when a tap coefficient applicable to the transversal type filter is needed, an impulse response of a propagation path can be estimated with a small amount of operations.

To put it more concretely, in mobile communication by a time division multiple access (TDMA) system, radio communication is performed by the use of a signal in which a signal that is known on both of the transmission side and the reception side and is called as a training sequence is inserted at the front of or the center of the data sequence of the signal. In this case, when the impulse response estimation device according to the present

embodiment is used, the Lattice filter 201 obtains backward prediction errors by the use of the aforesaid training sequence as an input signal sequence, and the tap coefficient calculation section 202 converges tap coefficient the inputs of which are the backward prediction errors. After the completion of the training sequence, the tap coefficient conversion section 203 converts the tap coefficient the inputs of which are the backward prediction errors to a tap coefficient applicable to the transversal type filter.

In such a case, because the impulse response estimation device according to the present embodiment performs the conversion of a tap coefficient including a matrix operation only one time, a tap coefficient applicable to the transversal type filter with a small amount of operations. Furthermore, because the Lattice filter performs a small amount of operations, the Lattice filter has convergence properties higher than those of the LMS algorithm that is frequently used. Consequently, because the impulse response estimation device according to the present embodiment can shorten the length of the training sequence, the impulse response estimation device can also improve the transmission efficiency thereof.

As mentioned above, according to the present embodiment, because a tap coefficient obtained by the use of a Lattice filter is converted to a tap coefficient applicable to a transversal type filter, an impulse

response of a propagation path can be obtained without the use of the RLS algorithm. Consequently, the impulse response estimation device according to the present embodiment can obtain an impulse response of a propagation path without the increase of the amount of its operations and in a state of having a high convergence characteristic. As a result, in a transversal type filter equipped with an impulse response estimation device according to the present embodiment, because a replica generated by the use of an impulse response of a propagation path obtained by the impulse response estimation device has high accuracy, a demodulated signal is a signal the deterioration of the characteristics of which owing to the influence of intersymbol interference is satisfactorily compensated.

(Embodiment 2)

As for the present embodiment, a case where an impulse response estimation device, which was described with regard to Embodiment 1, is loaded on a decision feedback equalizer in place of a maximum likelihood sequence estimation type equalizer is described. Hereinafter, a decision feedback equalizer equipped with an impulse response estimation device according to the present embodiment by reference to FIG. 5.

FIG. 5 is a block diagram showing the configuration of a decision feedback equalizer equipped with an impulse response estimation device according to Embodiment 2 of the present invention. Incidentally, the impulse response

estimation device 102 in FIG. 5 is the same impulse response estimation device described with regard to Embodiment 1.

In FIG. 5, a received signal inputted from an input terminal 401 is transmitted to a delay unit 402, a multiplier 405 and the impulse response estimation device 102. Delay units 402, 403 and 404 and multipliers 405, 406, 407 and 408 perform a convolution operation of the received signal from the input terminal 401.

That is, the delay unit 402 delays the received signal for one symbol time to transmit the delayed received signal to the delay unit 403 and the multiplier 406. The delay unit 403 delays the received signal delayed by the delay unit 402 for one symbol time to transmit the delayed received signal to the delay unit 404 and the multiplier 407. The delay unit 404 delays the received signal delayed by the delay unit 403 for one symbol time to transmit the delayed received signal to the multiplier 408.

Furthermore, the multiplier 405 multiplies the received signal from the input terminal 401 by a tap coefficient given by the impulse response estimation device 102 to transmit a signal generated by the multiplication of the aforesaid received signal and the aforesaid tap coefficient to an addition section 409. The multiplier 406 multiplies the received signal delayed by the delay unit 402 by the tap coefficient given by the impulse response estimation device 102 to transmit a

signal generated by the multiplication of the aforesaid received signal and the aforesaid tap coefficient to the addition section 409. Similarly, the multiplier 407 and the multiplier 408 multiply the received signals delayed by the delay unit 403 and the delay unit 404, respectively, by the tap coefficient given by the impulse response estimation device 102 to transmit a signal generated by the multiplication of the aforesaid received signal and the aforesaid tap coefficient to the addition section 409.

The addition section 409 adds the multiplied signals from the multipliers 405-408 and a signal from a multiplier 413 that will be described later to transmit a signal after the addition to a discriminator 410 as a demodulated signal. The discriminator 410 discriminates a code of the demodulated signal from the addition section 409 to output the demodulated signal after the discrimination from an output terminal 411 as a decoded signal, and further the discriminator 410 transmits the aforesaid decoded signal to the impulse response estimation device 102 and a delay unit 412.

The impulse response estimation device 102 receives the input of the decoded signal from the discriminator 410 as a reference signal and receives the input of the received signal from the input terminal 401 as an input signal. The impulse response estimation device 102 obtains an impulse response, i.e. a tap coefficient, of a propagation path by means of the aforesaid reference

signal and the aforesaid input signal to transmit the obtained tap coefficient to the multipliers 405-408 and the multiplier 413.

The delay unit 412 delays the decoded signal from the discriminator 410 for one symbol time to transmit the delayed decoded signal to the multiplier 413. The multiplier 413 multiplies the delayed decoded signal from the delay unit 412 by the tap coefficient given by the impulse response estimation device 102 to transmit a signal generated by the multiplication of the aforesaid decoded signal and the aforesaid tap coefficient to the addition section 409.

As described above, according to the present embodiment, by the use of an impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of operations, the decision feedback equalizer can take out a decoded signal by means of a small amount of operations, whereas the decision feedback equalizer has a high speed convergence characteristic.

(Embodiment 3)

In the present embodiment, a case where the establishment of synchronization is performed by the use of the impulse response estimation device described in regard to Embodiment 1 is described by reference to FIG. 6. FIG. 6 is a block diagram showing the configuration of a synchronous establishment device equipped with an

impulse response estimation device according to Embodiment 3 of the present invention.

In FIG. 6, a received signal inputted from an input terminal 501 is transmitted to a timing-adjusting unit 502 and an impulse response estimation device 102. A memory section 504 stores a known reference signal for synchronization in advance, and the memory section 504 transmits the reference signal for synchronization to the impulse response estimation device 102.

The impulse response estimation device 102 estimates an impulse response of a propagation path by the use of the received signal from the input terminal 501 as a reference signal and by the use of the reference signal for synchronization from the memory section 504 as an input signal. The impulse response estimation device 102 transmits the result of the estimation of the impulse response to the timing-adjusting unit 502. The timing-adjusting unit 502 performs the timing adjustment of the received signal from the input terminal 501 on the basis of an estimation result from the impulse response estimation device 102 to output the received signal the timing of which was adjusted.

In such a way, according to the present embodiment, by the use of an impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of operations, the establishment of synchronization in a higher speed can be

performed.

(Embodiment 4)

In the present embodiment, a case where radio communication is performed by the use of the impulse response estimation device described in regard to Embodiment 1 by reference to FIG. 7. FIG. 7 is a typical diagram showing a state when a base station apparatus equipped with an impulse response estimation device according to Embodiment 4 of the present invention performs the radio communication in the time division duplex (TDD) system with a mobile station apparatus. Incidentally, in FIG. 7, a channel estimation section 102 is the same as the impulse response estimation device described with regard to Embodiment 1.

In the TDD system, because the frequency bands to be used for transmission and reception are the same, a radio propagation environment at transmission timing and a radio propagation environment at reception timing can be regarded as being almost not different from each other. Now the radio propagation environments is designated by a reference character "H(z)".

When FIG. 7 is referred, a signal X(z) transmitted by a mobile station apparatus 601 is received by a radio section 603 in a base station apparatus 602 in a form of X(z)H(z). In the base station apparatus 602, the received signal is transmitted to the channel estimation section 102 through an equalization section 604.

The channel estimation section 102 estimates the propagation path H(z) by means of the received signal from the equalization section 604 to transmit the result of the estimation to the equalization section 604. The equalization section 604 decodes the received signal by means of the result of the estimation from the channel estimation section 102.

On the other hand, a inverse equalization section 605 multiplies a transmission signal Y(z) by the inverse characteristic $H(z)^{-1}$ of the propagation path H(z) estimated by the channel estimation section 102 to transmit a transmission signal multiplied by the inverse characteristic to the radio section 603. The radio section 603 transmits the transmission signal multiplied by the inverse characteristic.

The signal transmitted by the radio section 603 is received by the mobile station apparatus 601 in the following expression.

$$Y(z) \cdot H(z) \cdot H(z)^{-1} = Y(z) \quad - ③$$

As it is apparent from the above expression ?, the mobile station apparatus 601 can obtain the desired signal Y(z) without compensating the waveform distortion of the propagation path with an equalizer or the like. Thereby the load of the mobile station apparatus 601 can be decreased.

In the TDD system, because the time difference between the transmission timing and the reception timing

is little, the changes of the radio propagation environments in the transmission timing and in the reception timing are small, but the estimation of a propagation path is needed to be completed in a short time. When an impulse response estimation device according to the present embodiment is used, the necessary amount of operations can be small. Consequently, it becomes possible to end the estimation of a propagation path for a short time. Moreover, because the convergence properties are high, the high accuracy estimation of a propagation path can also be performed.

As described above, according to the present embodiment, by the use of an impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of operations, it becomes possible to provide a base station apparatus and a communication terminal apparatus (mobile station apparatus) that can realize good and high quality radio communication.

Incidentally, because it is preferable that the load of a mobile station apparatus is decreased as much as possible, a case where an impulse response estimation device is loaded on a base station apparatus is described in the present embodiment. However the present invention is not limited to such a case, but the present invention can be applied to a case where an impulse response estimation device is loaded on a mobile station apparatus,

too.

Furthermore, the impulse response estimation device described in the aforesaid embodiments, and various equalizers and synchronous establishment devices equipped with the impulse response estimation device can be loaded on a base station apparatus and a communication terminal apparatus in a digital mobile communication system.

① An impulse response estimation device of the present invention comprises: a Lattice filter for generating a backward prediction error sequence and a backward reflection coefficient from an input signal sequence; calculation means for calculating a tap coefficient by means of a reference signal and the backward prediction error sequence; and generation means for generating a transformation matrix by means of the backward reflection coefficient to generate a tap coefficient applicable to a transversal type filter by means of a matrix operation using the transformation matrix and the tap coefficient.

According to the configuration, because the tap coefficient obtained by the use of the Lattice filter is converted to the tap coefficient applicable to the transversal type filter, an impulse response of a propagation path can be obtained without using the RLS algorithm. Thereby the impulse response estimation device can obtain the impulse response of the propagation path without increasing the amount of its operations, whereas

the impulse response estimation device has a high convergence characteristic.

② A maximum likelihood sequence type estimation device of the present invention is equipped with the aforesaid impulse response estimation device.

According to the configuration, by the use of the impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations, the maximum likelihood sequence type estimation device can take out a decoded signal by a small amount of operations whereas the maximum likelihood sequence type estimation device has a high speed convergence characteristic.

③ A decision feedback equalizer of the present invention is equipped with the aforesaid impulse response estimation device.

According to the configuration, by the use of the impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations, the decision feedback equalizer can take out a decoded signal by a small amount of operations whereas the decision feedback equalizer has a high speed convergence characteristic.

④ A synchronous establishment device of the present invention is equipped with the aforesaid impulse response estimation device.

According to the configuration, by the use of the

impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations, the higher speed establishment of synchronization can be performed.

⑤ A communication apparatus of the present invention uses a result of an estimation of a propagation path by the aforesaid impulse response estimation device to equalization processing at reception or inverse equalization processing at transmission.

According to the configuration, by the use of the impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations to the equalization processing at reception or the inverse equalization processing at transmission, good and high quality radio communication can be realized.

⑥ A communication terminal apparatus of the present invention is equipped with the aforesaid impulse response estimation device.

According to the configuration, by the loading of the impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations, the communication terminal apparatus can take out a decoded signal by a small amount of operations whereas the communication terminal apparatus has a high speed convergence characteristic. Thereby a communication terminal apparatus that performs

good radio communication can be provided.

⑦ A base station apparatus of the present invention is equipped with the aforesaid impulse response estimation device.

According to the configuration, by the loading of the impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations, the base station apparatus can take out a decoded signal by a small amount of operations whereas the base station apparatus has a high speed convergence characteristic. Thereby a base station apparatus that performs good radio communication can be provided.

⑧ A communication terminal apparatus of the present invention is equipped with any one of the aforesaid communication apparatuses.

According to the configuration, by the equipment of any one of the aforesaid communication apparatuses, a communication terminal apparatus that performs good communication can be provided.

⑨ A base station apparatus of the present invention is equipped with any one of the aforesaid communication apparatuses.

According to the configuration, by the equipment of any one of the aforesaid communication apparatuses, a base station apparatus that can perform good radio communication can be provided.

⑩ A channel estimation method of the present invention comprises the steps of: generating a backward prediction error sequence and a backward reflection coefficient from an input signal sequence; calculating a tap coefficient by means of a reference signal and the backward prediction error sequence; and generating a transformation matrix by means of the backward reflection coefficient to generate a tap coefficient applicable to a transversal type filter by multiplying the transformation matrix and the tap coefficient.

According to the configuration, because the tap coefficient obtained by the use of the Lattice filter is converted to the tap coefficient applicable to the transversal type filter, an impulse response of a propagation path can be obtained without using the RLS algorithm. Thereby the channel estimation method makes it possible to obtain the impulse response of the propagation path without increasing the amount of its operations, whereas the channel estimation method has a high convergence characteristic.

As described above, according to the present invention, a transformation matrix is made by the use of a backward reflection coefficient generated by a Lattice filter, and a tap coefficient applicable to a transversal type filter by means of a matrix operation between a tap coefficient calculated by the use of a backward prediction error generated by the Lattice filter and the aforesaid

transformation matrix. Consequently, an impulse response estimation device capable of obtaining an impulse response of a propagation path without increasing the amount of its operations can be provided.

This application is based on the Japanese Patent Application No. HEI 11-363756 filed on December 22, 1999, entire content of which is expressly incorporated by reference herein.

Industrial Applicability

The present invention is suitable for the use of the field of an equalizer for compensating waveform distortion that is generated in a propagation path owing to a delay, and more particularly is suitable for the use of the field of an impulse response estimation device installed on an equalizer for obtaining an impulse response of a propagation path.

CLAIMS

1. An impulse response estimation device comprising:

a Lattice filter for generating a backward prediction error sequence and a backward reflection coefficient from an input signal sequence;

calculation means for calculating a tap coefficient by means of a reference signal and the backward prediction error sequence; and

generation means for generation a tap coefficient applicable to a transversal type filter by means of a matrix operation using the transformation matrix ,which is generated by means of the backward reflection coefficient, and the tap coefficient. .

2. A maximum likelihood sequence estimation type equalizer equipped with said impulse response estimation device according to claim 1.

3. A decision feedback equalizer equipped with said impulse response estimation device according to claim 1.

4. A synchronous establishment device equipped with said impulse response estimation device according to claim 1.

5. A communication apparatus using a result of an estimation of a propagation path by said impulse response estimation device according to claim 1 to equalization processing at reception or inverse equalization processing at transmission.

6. A communication terminal apparatus equipped with

said impulse response estimation device according to claim 1.

7. A base station apparatus equipped with said impulse response estimation device according to claim 1.

8. A channel estimation method comprising the steps of:

generating a backward prediction error sequence and a backward reflection coefficient from an input signal sequence;

calculating a tap coefficient by means of a reference signal and the backward prediction error sequence; and

generating a tap coefficient applicable to a transversal type filter by multiplying the transformation matrix, which is generated by means of the backward reflection coefficient, and the tap coefficient.

ABSTRACT

A Lattice filter 201 generates a backward prediction error and a backward reflection coefficient by the use of an input signal sequence. A tap coefficient calculation section 202 calculates a tap coefficient by the use of a reference signal and a backward prediction error signal sequence generated by the Lattice filter. A tap coefficient conversion section 203 makes a transformation matrix by the use of a backward reflection coefficient generated by the Lattice filter 201, and generates a tap coefficient applicable to a transversal type filter by mean of a matrix operation using the tap coefficient calculated by the tap coefficient calculation section 202 and the aforesaid transformation matrix.

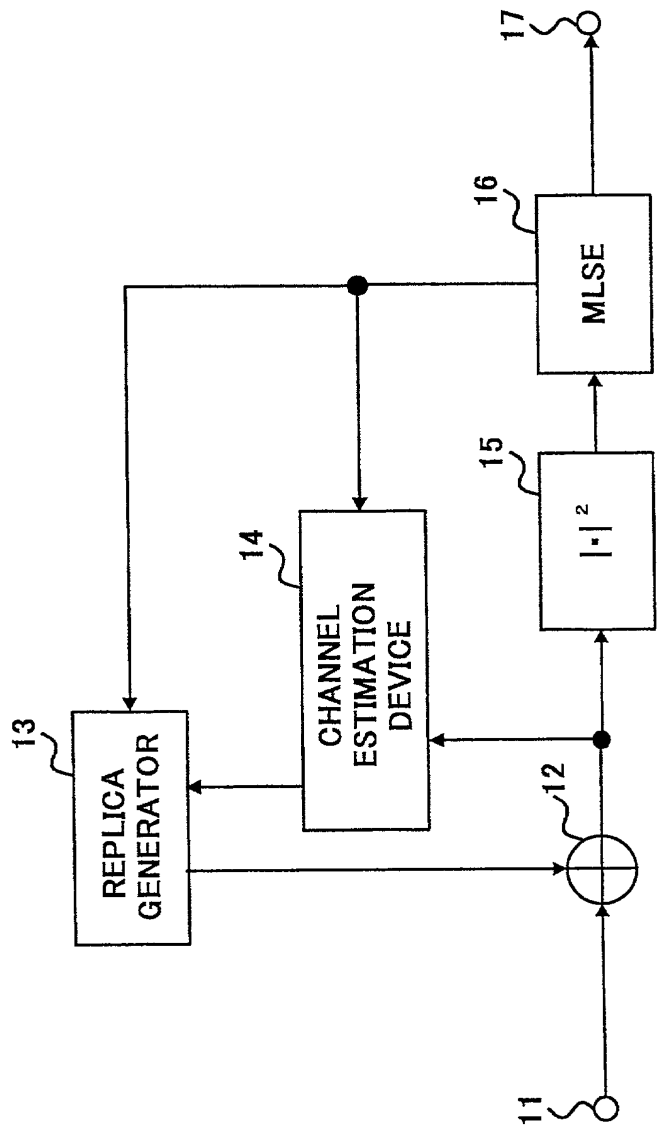
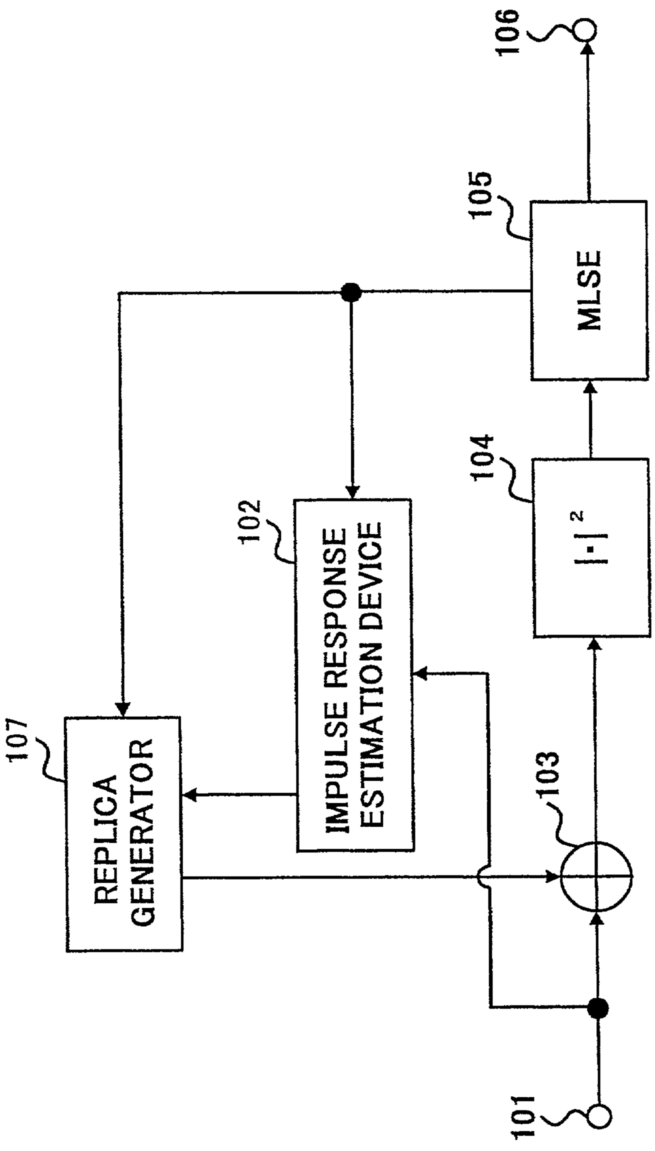

11
12
13
REPLICA GENERATOR
14
CHANNEL ESTIMATION DEVICE
15
|•|²
16
MLSE
17

FIG.1



106
105
MLSE
104
$|\cdot|^2$
102
IMPULSE RESPONSE ESTIMATION DEVICE
107
REPLICA GENERATOR
103
101

FIG.2

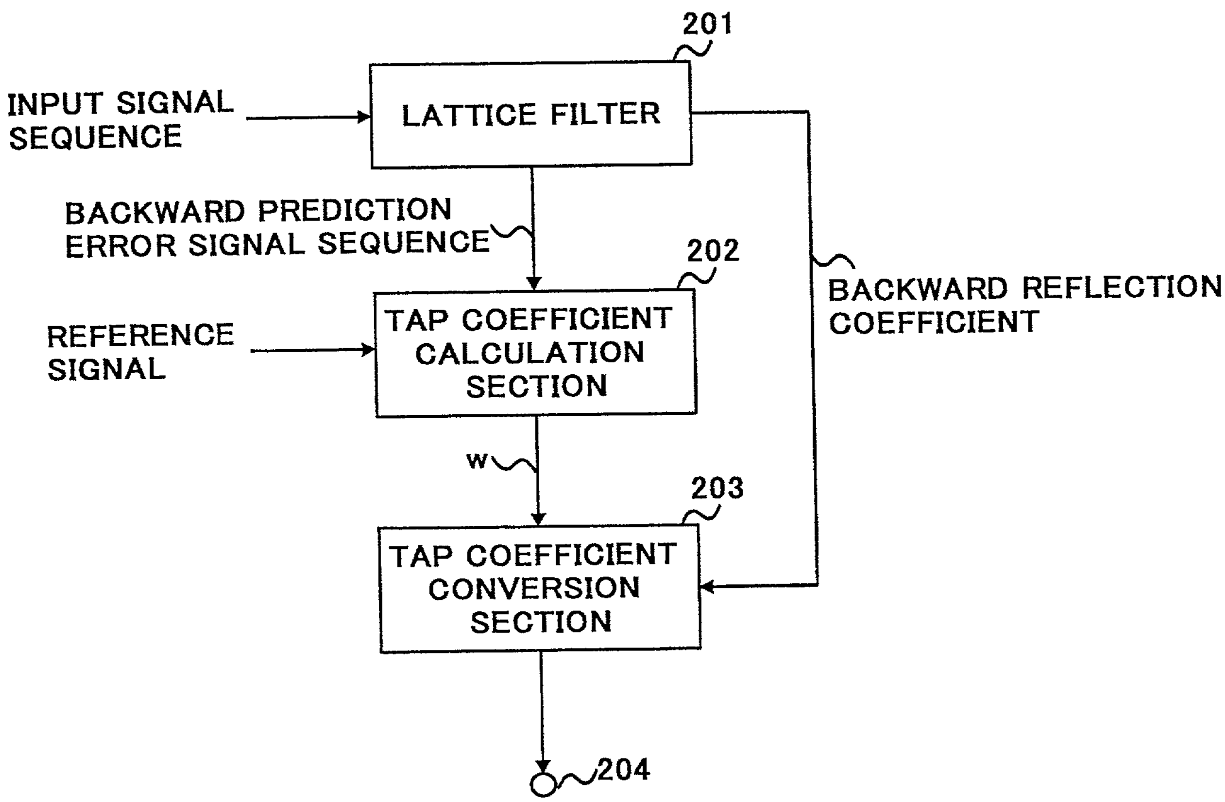
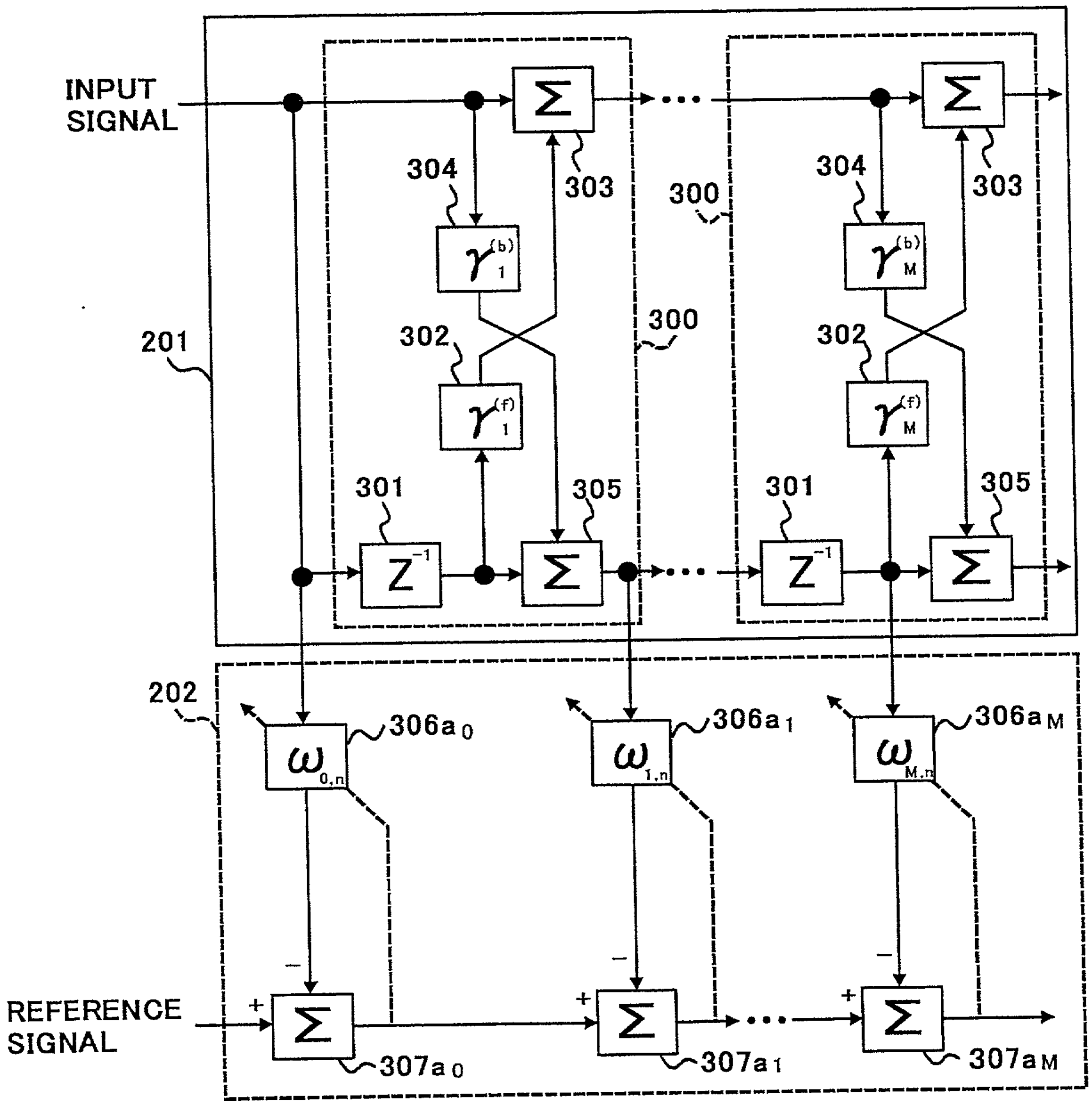

201
INPUT SIGNAL SEQUENCE
LATTICE FILTER
BACKWARD PREDICTION ERROR SIGNAL SEQUENCE
202
BACKWARD REFLECTION COEFFICIENT
REFERENCE SIGNAL
TAP COEFFICIENT CALCULATION SECTION
w
203
TAP COEFFICIENT CONVERSION SECTION
204

FIG.3



INPUT SIGNAL
REFERENCE SIGNAL
201
202
300
301
302
303
304
305
306a0
306a1
306aM
307a0
307a1
307aM

FIG.4

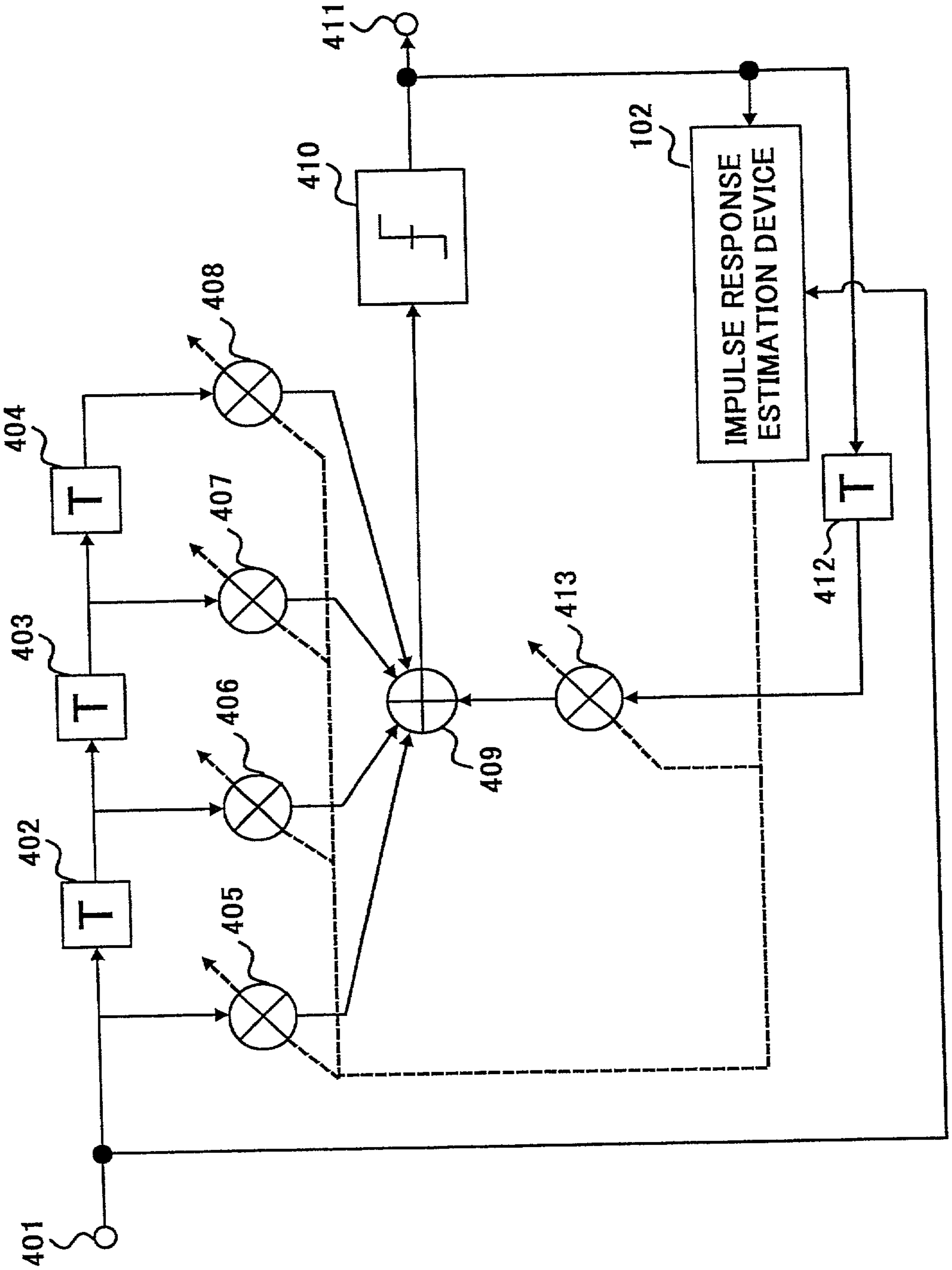

401
402
403
404
405
406
407
408
409
410
411
102
IMPULSE RESPONSE ESTIMATION DEVICE
412
413
T
T
T
T

FIG.5

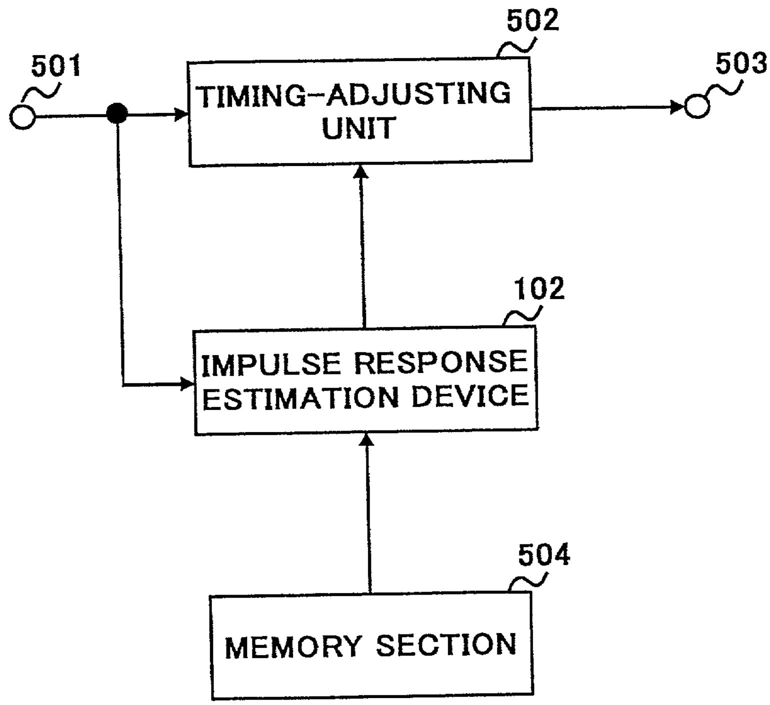

501
502
TIMING-ADJUSTING UNIT
503
102
IMPULSE RESPONSE ESTIMATION DEVICE
504
MEMORY SECTION

FIG.6

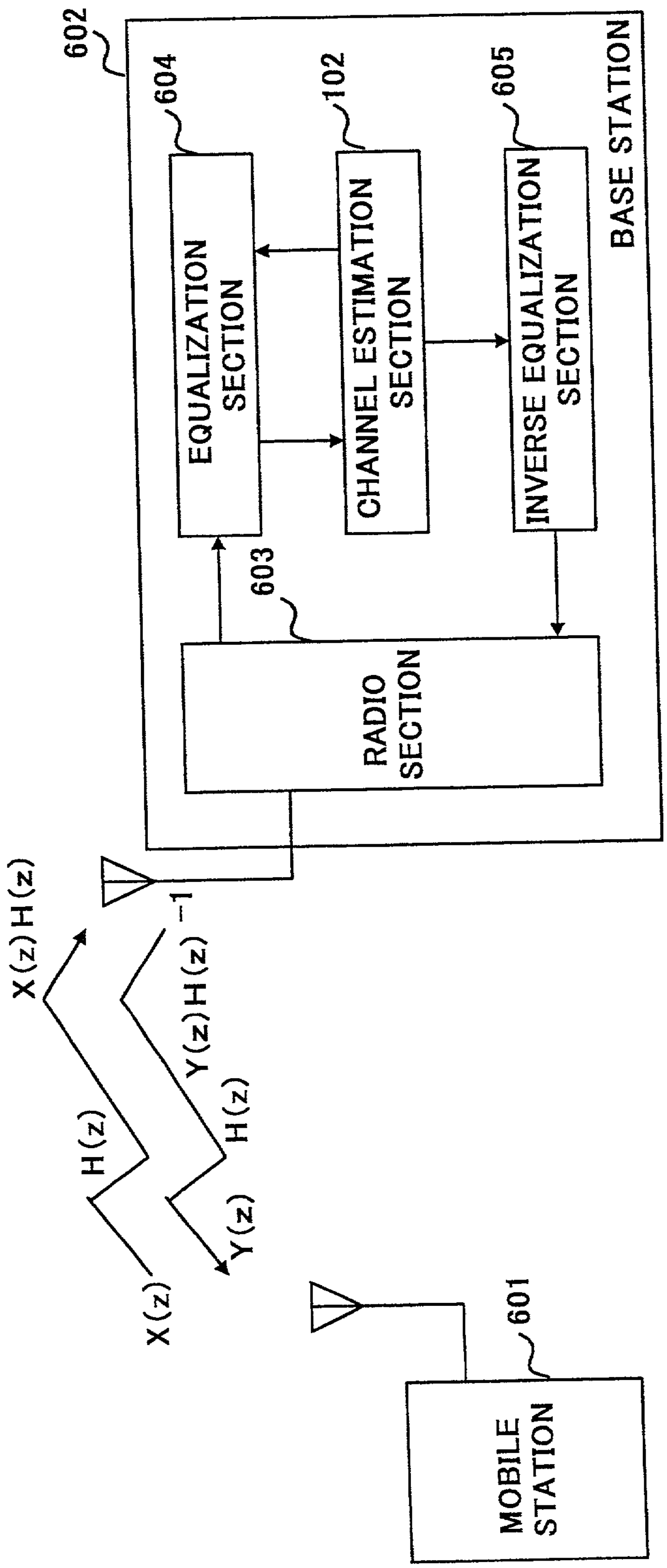

602
604
102
605
BASE STATION
EQUALIZATION SECTION
CHANNEL ESTIMATION SECTION
INVERSE EQUALIZATION SECTION
603
RADIO SECTION
X(z)H(z)
Y(z)H(z)^{-1}
H(z)
H(z)
X(z)
Y(z)
601
MOBILE STATION

FIG.7

APPLICATION FOR UNITED STATES PATENT
Declaration for Patent Application

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on

the invention entitled: IMPULSE RESPONSE ESTIMATION DEVICE AND CHANNEL ESTIMATION METHOD

the specification of which 2 (file no. ____________)

(check at least one) 3 [x] is attached hereto

4 [ ] was filed on __________ as (5) U.S. Application Serial No.__________

6 [ ] and was amended on ______________________

(if applicable)

Use this portion only if you are entering the U.S. National phase based on a PCT International Application designating the U.S.				
	7 [x]	was filed as PCT international application		
	8	Number **PCT/JP00/08801**		
	9	on **December 13, 2000**		
		and was amended under PCT Article(s) 19 and/or 34		
	10	on ______________________(if applicable).		
	11	priority date claimed in PCT International Application		
		JAPAN	**JP11-363756**	**22/December/1999**
		(Country)	(Number)	(Day/Month/Year Filed)
		(Country)	(Number)	(Day/Month/Year Filed)

I hereby declare that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended, by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me which is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application (s) for patent or inventor's certificate listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date earlier than that of the application(s) on which priority is claimed.

Prior (Foreign) Application(s) any Priority Claims Under 35 U.S.C. 119 — Priority Claimed

(Country)	(Number)	(Day/Month/Year Filed)	[ ] Yes	[ ] No
(Country)	(Number)	(Day/Month/Year Filed)	[ ] Yes	[ ] No

Priority Claim(s) from U.S. Provisional Application(s) - I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below:

Application No.	Day/Month/Year Filed	Application No.	Day/Month/Year Filed

Do not use this portion to identify a PCT application if the parent application is the U.S. National phase of the PCT application	I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) or PCT international application(s) designating the United States of America that is/are listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in that/those prior application(s) in the manner provided by the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose to the United States Patent and Trademark Office all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between filing date of the prior application and the national or PCT international filing date of this application. 13 (U.S. Application Number) (U.S. Filing Date) Status (patented, pending, abandoned)

I hereby appoint the following attorneys of the firm of Stevens, Davis, Miller & Mosher, L.L.P. as my attorneys of record with full power of substitution and revocation to prosecute this application and to transact all business in the Patent and Trademark Office:

James E. Ledbetter, Reg. No. 28732; Thomas P. Pavelko, Reg. No. 31689; and Anthony P. Venturino, Reg. No. 31674.

ALL CORRESPONDENCE IN CONNECTION WITH THIS APPLICATION SHOULD BE SENT TO STEVENS, DAVIS, MILLER & MOSHER, L.L.P., 1615 L Street, N.W., Suite 850, Washington, D.C. 20036, TELEPHONE (202) 408-5100, FACSIMILE (202) 408-5200.

See page 2 for signature lines

See other side for instructions for completing this form

STEVENS, DAVIS, MILLER & MOSHER, L.L.P.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful statements may jeopardize the validity of the application or any patent issuing thereon.

PAGE 2 OF U.S.A. DECLARATION FORM

14a	Typewritten Full Name of Sole or First Inventor	**Keiichi** (Given Name)	(Middle Name)	**KITAGAWA** (Family Name)
15a	Inventor's Signature	Keiichi		Kitagawa
16a	Date of Signature	July (Month)	16 (Day)	2001 (Year)
17a	Residence	**Yokosuka-shi** (City)	**Kanagawa** (State or Province)	**JAPAN** (Country)
18a	Citizenship	**JAPAN**		
19a	Post Office Address *(Insert complete mailing address, including country)*	**6-2-707, Hikari no Oka, Yokosuka-shi, Kanagawa 239-0847 JAPAN**		
14b	Typewritten Full Name of Sole or Second Inventor	Given Name	Middle Name	Family Name
15b	Inventor's Signature			
16b	Date of Signature	Month	Day	Year
17b	Residence	City	State or Province	Country
18b	Citizenship			
19b	Post Office Address *(Insert complete mailing address, including country)*			
14c	Typewritten Full Name of Sole or Third Inventor	Given Name	Middle Name	Family Name
15c	Inventor's Signature			
16c	Date of Signature	Month	Day	Year
17c	Residence	City	State or Province	*Country*
18c	Citizenship			
19c	Post Office Address *(Insert complete mailing address, including country)*			
14d	Typewritten Full Name of Sole or Fourth Inventor	Given Name	Middle Name	Family Name
15d	Inventor's Signature			
16d	Date of Signature	Month	Day	Year
17d	Residence	City	State or Province	Country
18d	Citizenship			
19d	Post Office Address *(Insert complete mailing address, including country)*			

*Note to Inventor: Please sign name on line 15 exactly as it appears in line 14 and insert the actual date of signing on line 16. If there are more than four inventors, please add a copy of this page for identification and signatures for the additional inventors.

INSTRUCTIONS FOR COMPLETION OF THIS FORM

line 1 Insert the same title as is used on the specification and in the assignment.

line 2 Is optional but is provided so that you can use it to identify more readily an application prior to the time that the Patent Office application serial number is assigned. We suggest that the specification, drawings and declaration always bear a file number since it can help to get the papers together in case they become inadvertently separated. In instances where the specification is filed without a signed declaration form (under 37 CFR §1.53) a file number on a later-received separate form will assist us in associating it with the correct case.

line 3 Check this box if the specification, claims and drawing (if any) are attached to this declaration form, e.g., when filing a new patent application.

lines 4-5 Are only used in an instance where the application is already on file and the declaration from is being separately filed, e.g.,when the application was originally filed without a signed declaration or where the Patent Office has required a new declaration because of a deficiency in the original declaration. In such an instance the Patent Office will require that lines 4 and 5 be completed with the filing date and application serial number already assigned.

line 6 Is used in conjunction with line 5 but only when there have been one or more amendments to the specification or claims. Line 6 is also used when the Examiner requires a new declaration because claims inserted by amendment cover subject matter not originally claimed (37 CFR §1.67).

lines 7-11 Are for PCT (Patent Cooperation Treaty) cases and are used only when you are entering the U.S. National phase (Chapter I or II) based upon a previously filed PCT International application designating the U.S.

line 7 Check this box if this is a PCT National Phase application.

line 8 Insert PCT International application number.

line 9 Insert date of filing of PCT International application.

lines 10-11 Insert the date of all amendments filed in the PCT International application. Such amendments are optional, so this line at times will not be used.

line 12a Is used in the following instances:

(i) If a single priority is being claimed from a foreign application you need to list only the first-filed application; you do not need to list other countries if all applications were filed within one year of the U.S. filing.

(ii) If multiple priorities are being claimed, from a plurality of applications filed in one or more countries, you must list the first filed application for each aspect of the invention. Example: if aspect A of the invention was disclosed in an application filed 11 months earlier in country X and aspect B was disclosed 9 months earlier in an application filed in country Y, then the applications in both countries X and Y must be identified. Only the first application for each aspect of the invention needs to be identified provided all applications on that aspect were filed within one year prior to the U.S. filing.

(iii) If a non-priority application is being filed you must list all applications in all countries where corresponding foreign applications were filed more than one year prior to the U.S. filing. This is so the Examiner can check to see if any of those applications were published or patented early enough to be prior art against the U.S. application.

(iv) If there are more than two applications to be listed we suggest that you type in on this form only "See attached Schedule A" and then list all of the previous applications on an attached sheet.

line 12b Is used to claim priority under 35 USC §119(e) based on a provisional application filed within one year of the filing of the instant application. More than one provisional application may be identified provided neither was filed more than one year earlier.

line 13 This block is used only in instances where there is a previously filed U.S. non-provisional application which was copending at the time the present application was (or is being) filed. that previous application could be a U.S. non-provisional application or the National Phase of a PCT allocation. In such a case the present application may be entitled to the priority of the previous application's U.S. filing date (and consequently the foreign priority thereof) provided the present application is identified as a continuing application (continuation, divisional or continuation-in-part) of the earlier (parent) application. If the foregoing is applicable, please fill in one line for each such prior application.

line 14 Type the inventor's proper legal name in the order specified, e.g., "John B. JONES" or "J. Bob JONES" if the inventor so prefers. It is not acceptable to use only initials such as "J. B. JONES."

line 15 The inventor's "signature" may be his (or her) usual manner of signing but it is preferable that the inventor simply write his (or her) name in his (or her) own cursive handwriting in the same order as on line 14, e.g., given name, middle initial and Family name.

line 16 Insert the actual date of signature.

line 17 Insert simply the city and state or country, e.g., "Paris, France", of the inventor's residence, not citizenship. No street address or postal code is required on this line.

line 18 Insert the inventor's citizenship. The statement of citizenship (or subject of) is a statutory requirement (35 USC §115). Simply the name of the country of citizenship, e.g., "Japan" is sufficient.

line 19 Insert the inventor's mailing address. The purpose of requiring the post office address is to enable the Patent Office to communicate directly with the inventor if desired, such as in the case of death of the U.S. attorney. It should be the address where the inventor customarily receives his (or her) mail and should include the postal code. If applicable it can be the inventor's business address or address at place of employment.

Applicants are reminded that the U.S. Patent and Trademark Office has very strict requirements as to proper execution of an application. The applicant should make sure that he reviews the declaration, prior to signing to make sure the declaration properly identifies the application and all relevant information; and should review the specification and claims (including drawings, if any) before signing the declaration. Failure to do so will require the filing of a supplemental declaration --- 37 CFR §1.67(c).

Any handwritten changes to the specification, claims or drawings must be in ink personally by all of the inventors prior to signing the declaration and the adjacent left margin must be initialed and dated by all of the inventors, e.g., "JBJ 6-9-91".

Please let us know if there are any questions regarding proper completion of this form. Thank you.

An assignment, a separate document requiring separate signature and dating may be enclosed. Please look for it and sign and date it in the same manner as in lines 15 and 16 above.